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THE SURVEILLANCE OF STORED ITEMS

BY

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1. Background

Part of the responsibility of all branches of the military services is to maintain an adequate supply of usable materials of all types so that in any emergency a sufficient quantity of materials will be on hand in the war reserve stocks to enable the Department of Defense to meet the needs of a military action of some minimum length. In order to carry out this responsibility, all branches of the service purchase equipment, repair parts, replace parts and supplies, and maintain them in stores ready for issue at any time. These supplies can be classified in many ways, and the first general classification breaks them down into

1. Current supplies (supplies that are constantly being used and replaced through the procurement of new supplies.)
2. War reserve stocks (supplies and equipment maintained in stores and warehouses against the needs for emergency issue.)

All types of materials and equipment deteriorate to some extent in storage; some materials deteriorate at a much more rapid rate than others. Some materials change in characteristics as time passes regardless of the environment in which they are stored and the protection afforded them. Certain chemical compounds (rubber, for instance) behave in this fashion. On the other hand, the deterioration rate of most supply items can be regulated or partially controlled by controlling the environment in which the material is stored. The environment includes such factors as temperature, humidity, direct

sunlight, fumes or gases that cause corrosion, and physical protection against damage (crushing under high stacks, blows from trucks, fire, and theft). It is necessary, then, for the military to recognize the difference in behavior of the items under different environments and to take whatever precautions are necessary to maintain the items in usable condition. In spite of all attempts to maintain the items in usable condition, deterioration does take place and at varying rates which cannot be totally accounted for by relating the rates to environmental conditions. The surveillance problem, then, is that of determining the condition of the materials in storage and making a decision as to what disposition shall be made of it.

A number of objectives can be set forth for any surveillance program. The foremost objective is to determine the conditions of the items in storage in order that the proper action can be taken to insure an adequate supply of usable items according to the estimated military needs. The condition of the materials as revealed by the surveillance inspection will dictate the proper action:

1. Retain as is
2. Inspect 100%, repair or recondition as necessary
3. Represerve and repackage after cleaning off corrosion or rust
4. Scrap and replace through new procurement.

These decisions are similar to those that must be made by acceptance procedures regarding newly procured items except that in surveillance the decision to accept simply means that the quality of material in storage is good enough to continue in storage without additional inspection or repair. Thus the surveillance inspection is a special case of acceptance procedures in which there is no producer-consumer relations except as the quality affects the relations between the supply organization and the using organization.

A second objective is to obtain sufficient information about the variation in deterioration rates under different conditions so that an economical surveillance program can be planned that will accomplish the first objective. If items do not deteriorate rapidly, it is usually a

waste of money to go into detailed inspections at frequent intervals. When items deteriorate rapidly or at unknown rates it may be necessary to inspect more frequently or to base the frequency of inspection on the deterioration rate as observed. Thus, this objective is to determine what program would be most effective and to formulate inspection procedures and sampling plans that will enable decisions to be made currently which will minimize the cost of maintaining the desired stock of usable items.

A third objective of the surveillance program is to secure information about stability and reliability of materials and designs for the benefit of military designers and specification writers. This information will enable these people to alter future designs and specifications so that the items will have a longer shelf life and in turn involve less surveillance. This objective might be stated another way: to provide information that will reduce or eliminate the surveillance problem in the future. It, of course, depends upon adequate communications with procurement divisions and a willingness on the part of procurement to take advantage of the accumulated knowledge.

It is quite obvious that the formulation and operation of a satisfactory surveillance program is primarily a management and organization problem. The effectiveness of our fighting forces is largely dependent upon having an efficient and effective surveillance program. Each branch of the service has literally thousands of items to be stored and observed. These items fall in hundreds of classifications and present many, many different kinds of problems. Each item is important to the overall defense program. Lack of an inexpensive repair part can render a military unit immobile or ineffectual in performing its mission. Therefore the value of the item is not a criterion for a satisfactory surveillance program. There are other more important criteria that must be used in setting up such a program. The magnitude of the problem is such that the formulation of an efficient program is essential and offers the opportunity to save large amounts of money without impairing the effectiveness of the defense program.

2. Criteria for a Satisfactory Surveillance Program

A condensed statement of the criteria for an acceptable surveillance program might be simply that it will assure the services an adequate number of usable items on hand at any time to meet the needs for military action at a minimum cost of money, manpower and national resources. While such a statement provides general guidelines for planning, it gives little direct assistance in formulating or evaluating a proposed program. Individual factors must be considered more fully.

A usable item must be defined in some way. For procurement purposes detailed standards and specifications are commonly used in order to assure that the item supplied by a vendor is what the military agency wants or needs and that it will fulfill the functional requirements with the proper life, durability and accuracy. It should be quite obvious that the specifications and standards for usability of an item that is already owned by a military service will be somewhat different from those used in initial procurement. As one military representative put it, "You would not discard or scrap a truck because the paint is faded or because it had dents in its fenders, yet you would not buy a new truck from a supplier if it were in the same condition." The condition might not even be bad enough to justify a new paint job. Furthermore, even if the functional operation was below the standard for new trucks it is more economical to repair the truck than to purchase a new one. In many military operations it is better to have a weapon or a device that works at some inferior rate than to have none at all. These ideas introduce the concept that "usable" quality needs to be defined in reference to the items under consideration and that the definition may change with changes in the military situation relative to the available supply.

Another concept that must be considered in designing a surveillance program is that of the risk involved. Most stored items will have some defectives or defectiveness present, and one of the purposes of the surveillance program is to determine how defective the items are. Since sampling will usually be used as a basis for judging the defectiveness and deciding upon the disposition of stored items there is a certain

risk that the defectiveness will be underestimated and that lots of items will be retained when they should be 100% inspected and defectives repaired or removed. The probability of retaining too many defectives in stock is the risk involved in sampling.

At the same time, the information obtained in sampling can be used to estimate the rate of deterioration. By knowing the defectiveness of the lot at any one time and the rate of deterioration, the defectiveness at any future time can be estimated. This aspect is important to the military because it permits the frequency of inspection to be governed by the sensitivity of the material.

Another aspect of risk is encountered in the chance that a defective item will be issued to a using unit. When a large number of similar items are issued to one unit, the presence of a small percentage of defective or unusable items may be of almost no consequence. However, where an individual item is issued to a unit, as for instance a machine gun to an infantry squad, and where the unit's effectiveness depends upon the item's being good, we would not be willing to take as great a risk that some given percentage of the items were defective. Therefore, it is necessary to state the risk in any surveillance procedure by specifying the quality level, an AQL (Acceptable Quality Level) or AOQL (Average Outgoing Quality Limit), that it will provide. The AQL or AOQL should be specified for each type or classification of item so that the appropriate surveillance plan can be used.

The selection of specifications for usable quality and the AQL to be used must be made with reference to cost and probable consequences incurred. The cost must be measured in terms of man-hours of labor that will be involved in the reinspection of the items. This is a function of two variables, the completeness of the inspection on each individual item and the number of items so inspected out of a given lot. The tighter the specifications for usable quality are, the more time must be devoted to the inspection of each item. The less risk we are willing to take, the smaller the AQL or AOQL must be and the larger the sample size must be for a given lot size. Also, more acceptable

lots will be rejected by tight plans, and therefore the frequency with which lots must be 100% inspected increases. This is in turn accompanied by more repair and rework of defective items. There is no question but that tight specifications and low risk plans result in a higher percentage of the items being in a usable condition, but it has been accomplished at a cost of increased man-hours and use of facilities.

The cost of increased protection, as described in the previous paragraph, should be considered in connection with the initial cost of the item and the time required for procurement of replacement items. Certain branches of the military service have set up arbitrary limits on the amount of money that may be spent on rework or overhaul of reparable items. One branch, for example, has specified that if the estimated cost of repair exceeds 40% of the initial cost the item will be reviewed by a special board that will make the decision as to whether the item should be repaired or scrapped. Some military representatives have expressed the opinion that surveillance costs exceed the cost of new items (in certain classifications) and that periodically new items should be purchased and the old items scrapped without interim inspection. The objective should be to select the largest AQL that the military can afford to accept for each classification of material and then to determine the surveillance procedure that will provide that amount of protection at the lowest total cost. This total cost should include the purchase price, the cost of special handling for surveillance purposes, the cost of the sampling inspection and final action. If the sum of the special handling costs, the inspection costs and the costs of the final action equal the cost of replacement (the purchase price), then surveillance should be abandoned and the items scrapped periodically.

This paper does not attempt to introduce or solve the so-called inventory problem of how much to order and the procurement problem. It is limited to the surveillance problems of items already on hand at any time. The surveillance problem and the inventory problem are by necessity interrelated, but the inventory problem is subject to straightforward

solution provided the surveillance program has supplied the information on shelf life and deterioration so that the prospective usable quantity can be predicted.

3 <u>Who Should Set Standards for Surveillance</u>

The problem of setting standards and specifications against which stored items will be compared must fall on the military. Representatives of the fighting forces must decide how bad an item may be before it becomes unusable. Only the using organizations are in a position to evaluate the effects of defective items upon the accomplishment of the assigned missions. The decision must be made for all the kinds of items. For example, powder and propellants change somewhat in burning rate and explosive power with age. How much change can be tolerated before the propellants constitute a hazard rather than a weapon? There is some point at which the firing tables used by artillery men would become totally useless, and, in time of war, there might not be time to compute new tables based upon the new characteristics of the propellants. In this case some change could be tolerated. However, in the case of an electronic guidance system for a missile, very little change in the electronic characteristics probably would render the system completely useless.

For most military supplies and equipment a classification of defects has been established for procurement purposes. This classification of defects becomes a basic consideration in surveillance programs. Responsible personnel should review the classification in order to determine which defects should be inspected in the surveillance operation and whether or not the classification can be down-graded. Some defects that were "critical" for procurement purposes may be considered as "majors", and some that were majors may be only "minors" in surveillance work. As in procurement, an AQL can be assigned by classifications for surveillance purposes. If a reclassification of defects is not feasible, then new and broader tolerances may be specified for the different characteristics that may be subject to deterioration. A combination of these two methods may be

employed in order to establish definite standards for the guidance of surveillance personnel.

To summarize, as long as items that will not pass the specifications for new items are considered usable (without repair or rework), it is necessary to have two sets of specifications and standards. One set must be very complete and suitable in every respect for procurement purposes. This set will normally require higher quality standards than are necessary for usability because allowance must be made for deterioration in storage. The other set must deal with all those characteristics that are subject to deterioration, and must set the lower limits for usability. Without definite standards the surveillance program cannot be expected to function effectively nor to assure that items in storage are usable.

4. What Items Should Be Included in the Surveillance Program?

It has been stated previously that all items of military stores play some part in the whole defense scheme, but it is obvious that, with the millions of items in storage, all items cannot and need not receive the same consideration in the surveillance program. It becomes necessary to expend the available money and resources on those things that are the most important to the defense program and which are also subject to deterioration at a rapid or an unknown rate. This has already been accounted for in many of the surveillance programs in that shelf life has been established and once the shelf life has been exceeded the item must either be inspected and up-dated if still in a satisfactory condition or be scrapped.

Practically all of the manufacturers of military supplies and equipment are aware of the characteristics of their products and are able to provide some guidance to the military regarding the probable shelf life. Manufacturers of preservatives and packaging materials know a great deal about how their products retard the deterioration of various kinds of materials. Furthermore, the military has a great deal of information from past experience with all kinds of materials stored

under widely varying conditions. From all of this information the military should be able to determine with a great deal of certainty which items would be most subject to deterioration when afforded various kinds of protection and preservation. Obviously, those items that have a long shelf life or which are not subject to deterioration when properly stored should be excluded from the surveillance program. The available money and facilities should be devoted to those items that either deteriorate rapidly or deteriorate at an unknown rate. Records should be kept to accumulate information on the latter group so that unnecessary surveillance can be avoided in the future.

Another factor in determining the items to be included is the time for replacement or repair of defective items. This factor also affects the risk that one is willing to take on an item being defective. The replacement time should be considered in reference to the size of the war reserve stock pile. The stock pile of usable items should be large enough at any time to conduct a military action of some specified duration. The duration should be long enough to permit the replacement of the items as they are used so that the military action can be continued without interruption. Consequently, there will be wide variations in the relative size of the war reserve stocks. Items common to both civilian and military activities need not be held in such large quantities as the items that are of purely military nature because they can be replaced more quickly. The required stock pile may be established in most instances relative to the estimate of the military situation. In other words, in times when war seems more imminent stock piles have been increased and as the danger of war decreases the stock piles have been allowed to dwindle. Furthermore, obsolescence tends to affect the amount of material that should be retained in stock. For example, when a new aircraft is procured in quantity and added to the fleet, the spare parts, wings, tanks, engines, landing gears, and other components are procured for replacement during the estimated life of the plane. As this plane is phased out (or as planes are lost due to accidents or military action) and replaced by newer types, the quantity of spare parts in stores is reduced accordingly.

5. Inspection Plans that Meet the Requirements and the Objectives of the Surveillance Program

The primary purpose of this paper is to analyze the surveillance problems so that appropriate inspection plans can be selected. It is necessary to establish the criteria for such inspection plans so that they can be adapted to the varying conditions and requirements of the several branches of the military service. It has been assumed that a surveillance program calls for sampling inspection plans. It is not likely that a single plan will satisfy all of the needs. Therefore, this paper proposes that certain characteristics of sampling plans be considered in reference to the individual problems that are encountered and that certain recommendations be made regarding the nature and use of the plans.

There are two broad classifications for acceptance sampling plans which may be considered for the surveillance problem. One type is the lot-by-lot type and the other is the continuous sampling type. The military has a large number of sampling acceptance plans of both these types. Since the problem of surveillance is concerned only with material already on hand (and not with product being submitted item-by-item as produced), the continuous plans appear not to be applicable, but later in this paper a three decision continuous plan is presented that appears to have some merit in the surveillance program.

Lot-by-lot acceptance plans take many forms. Attribute plans, typified by MIL STD 105A, are best known to inspectors and quality control personnel. Lot-by-lot plans based on variables (standard deviation or range) are coming into more wide-spread use. The government is issuing a variables standard, MIL STD 414, similar to MIL STD 105A for use in procurement. A third type of acceptance plan based upon lot-by-lot considerations, is the multiple or sequential type of plan. There are numerous individual sets of multiple plans in MIL STD 105A.

As has been stated earlier in this paper, it is necessary to establish the level of protection desired from any sampling plan. The

operating characteristic curves of existing lot-by-lot plans have been established for use in procurement inspection. As in procurement inspection, the lo are identified and are made up of product that was produced under essentially the same conditions and can be assumed to represent a homogeneous collection of items. If the same plans are to be used for surveillance programs, it must be reasonably possible to make the same assumptions about the items to be inspected. This, of course, immediately poses a major problem in many stored items, in that the identity of the lots is not necessarily retained after the item has been received and put into stores. In many cases it is still true that the lots are retained separately from other lots, so that the manufacturer, date of production and other information is available for use. On the other hand, many times the items have been moved from one warehouse to another or have been issued to using commands and returned, either used or unused. Practical problems of materials handling in the warehouses or depots preclude the possibility of reestablishing the original lots, and even if the lots were reassembled, the differences in the environments to which the several sublots have been exposed would mean that the whole lot could not be assumed to be homogeneous. This means that the warehouses and depots throughout the world have collections of items of similar nature, model, stock number, etc., yet produced by different manufacturers at different times and under different conditions, and are not homogeneous. The question then arises as to whether or not sampling plans based upon the assumption of homogeneous lots can be relied upon to give the desired protection when the question is "Is a sufficiently large percentage of these items usable to warrant their retention without further inspection and overhaul?"

It is safe to say that if all of the items in the collection, even though from different manufacturers, were made to the same original specifications with the same kind of materials and received essentially the same treatment, the errors resulting from the application of lot-by-lot acceptance plans would not necessarily preclude the use of such plans for surveillance purposes. If, however, there are substantial

differences in the design or materials it may be necessary to subdivide the groups according to some model number or serial number in order to apply the sampling plans with confidence. This can be somewhat verified by considering the mixing of two or more chip distributions. If the different distributions have approximately the same mean and only slightly different standard deviations, samples drawn from the thoroughly mixed chips will still tend to indicate the same average and a dispersion slightly larger than that of any one of the distributions. Thus, if a collection of items is made up of items that were originally very similar, and if they have had about the same treatment, a sample drawn from this collection should still indicate the average condition with some indication of the variation in quality that might be expected. Of course, under such conditions, it is very important to actually randomize the sample, and not to succumb to the temptation to take the items that are on top, or are convenient, as a sample. If some items have been subject to different environmental conditions, it would be desirable to make sublots from the large collection, basing the sublots upon the treatment received and not upon original manufacturer.

After an AQL has been selected for any item, it is necessary to consider the steepness of the operating characteristic curve in selecting the sampling plan to be used. The O.C. curves of many different sampling plans provide the same AQL, but, according to the steepness of the curves, provide more or less protection against accepting the lot at quality worse than desired. In surveillance work, this means that the steepness of the curve will determine the probability that an error would be made in deciding that the lot of material is usable when actually it is worse than the desired protection level. It is advisable, therefore, to choose two points through which the O.C. curve must go, one representing the AQL and the other the quality (p') which you are willing to accept only with a very small probability, say 10%. This second point corresponds roughly with the Lot Tolerance Percent Defective (LTPD) concept of the Dodge-Romig acceptance plans. These two points will essentially determine the steepness of the O.C. curve and enable one to

pick a satisfactory plan.

Consideration of the fraction defectives that will be accepted at the AQL and the LTPD immediately points out the problem of cost. As either or both the AQL and LTPD are reduced the sample size must increase, and the inspection cost must go up. The benefits that may be derived or the penalties that may be incurred at different AQL's must be weighed against the costs involved.

Where the important characteristics of the material under surveillance are measurable, it is probable that acceptance plans based upon variables will provide the desired amount of protection with less total inspection. The variables plans require a smaller sample size for a given AQL than do the attribute plans, but the cost of each inspection is usually greater. In many cases the characteristics under observation must be measured anyway, and it is foolish to throw away the extra information in order to use attribute plans. Such tests as functional tests for engines and air compressors, fuel consumption, hardness, tensile strength, rate of climb, recovery rates, etc., represent the best opportunities for use of variables plans.

The sequential type sampling plans appear to offer special advantages for surveillance purposes. Sequential type sampling plans may be either item-by-item or multiple sequential. That is, the decisions may be made after each item is inspected or after each group of n items is inspected. The decision must be one of three: accept, continue inspection, or reject. If lots are either very good or very bad the decision to accept or to reject can usually be made with a small amount of inspection. It is only when the actual quality is borderline that the sequential plans require a large amount of inspection. For these reasons it appears that sequential plans are particularly advantageous in surveillance work where the main problem is to guard against retaining lots of material as usable when the defectiveness is greater than some given percentage.

MIL STD 105A provides a set of multiple sequential sampling plans with eight possible steps in each. The sample sizes are substantially

smaller than the single sample sizes for corresponding protection. These plans are well known and are most valuable where the lot size is relatively large. Thus, in surveillance work, these plans would be most useful for checking the quality of component parts that are stored in fairly large quantities. In addition, if the items were all good at one time (when purchased) and if they deteriorate at about the same rate, a small sample can usually tell whether or not the fraction defective is greater than some arbitrary amount.

In those cases where the total quantity in storage is small or where the individual lots are small, a modified item-by-item sequential acceptance plan will usually be more economical. This is particularly applicable where the items are large, complex units and where the cost of an individual inspection is large. The disadvantage of the item-by-item plan lies in the necessity to compute a probability ratio after each item is inspected, or else to have previously prepared tables or charts for the particular protection desired from the plan. In item-by-item sequential plans, one item is inspected and a decision is made to accept or reject the lot or to inspect another item. It may, depending upon the protection desired, be necessary to examine several items before it is possible to either accept or reject the lot. (In other words, some minimum number must be inspected in most cases before a decision can be made to accept or to reject.) The total number of items to be inspected before a final decision to accept or to reject depends upon the quality of the lot and the chance variations of sampling. In practice these plans are usually modified to the extent that the procedure is truncated after a finite n items have been inspected.

I. Richard Savage, in his reports Cycling and A Three Decision Continuous Sampling Plan For Attributes* has proposed two models that

* Savage, I. Richard, "A Three Decision Continuous Sampling Plan For Attributes", Applied Mathematics and Statistics Laboratory, Stanford University, Contract N6onr-25126, Technical Report No. 20, January 22, 1955.

Savage, I. Richard, "Cycling", Applied Mathematics and Statistics Laboratory, Stanford University, Contract N6onr-25126, Technical Report No. 27, March 9, 1956.

appear to have some applications in surveillance work. His three decision model is designed for acceptance inspection of product from a continuous process, but with a little imagination it is easy to visualize its application to a lot of product that has been assembled from previous production. The procedure of the plan quoted directly from Technical Report No. 20 is as follows:

"The proposed procedure depends on four positive parameters, h_1, h_2, s, and K in the following manner.

"A: When the production process begins, start with 100 per cent inspection and let d_n be the number of defectives out of the first n items produced. As long as

$$-h_1 + sn < d_n < h_2 + sn \quad (0 < s < 1)$$

continue 100 per cent inspection.

"B: If $d_n \leq -h_1 + sn$ before $d_n \geq h_2 + sn$, stop 100 per cent inspection and accept a lot of size K (the next K items produced).

"B': If $d_n \geq h_2 + sn$ before $d_n \leq -h_1 + sn$, stop the production and attempt to improve the level of production.

"C: Eventually either B or B' will occur. When the appropriate action has been taken, start the inspection procedure over again by going back to A as if the production process had just begun."

One unusual assumption is made: the defective items found while inspecting at 100% will not be replaced by good items, but will be set aside and kept separate from the items passed. Otherwise, this plan is a rather special case of sequential acceptance procedures, with a specific limit, K, on the number of items to be accepted. Savage worked out an example in the Report using $h_1 = h_2 = 2$, $s = .1$, $K = 25, 50, 75$ and provided graphs to show the operation of the plan.

If a lot under surveillance is known to have been produced under a state of control and the lot has been subject to the same treatment so that it should still be homogeneous, this plan could be used with reasonable confidence. Since the lot has probably been well mixed during the process

of shipping and storing, the 100% inspection could be started at any convenient point in the warehouse and adjacent items inspected until the decision has been reached. If condition B is reached first, 100% inspection would be stopped and the next K items of the lot accepted as being usable. Then 100% inspection is instituted again until condition B or B' is reached. If condition B' is reached first, the lot is assumed to have more than some fraction of unusable items and should be submitted to 100% inspection and repair as necessary.

On page 21 of Report No. 27, Cycling, Savage presents "A Preparedness Problem" that results in an economic model for the determination of the frequency of inspection and repair of reserve equipment. He admits that the greatest difficulty may be the determination of the cost and loss information necessary for the solution, however, such a model should be helpful in determining policy on frequency of inspection and repair of major equipment. The following is a direct quote from the Report.

"A certain piece of equipment is kept in storage to be used only in the case of emergencies. While in storage it costs A units of money to inspect the equipment and $F(x)$ units of money to repair (like new) the equipment if it has been x units of time since the last inspection and repair. The costs A and $F(x)$ apply only if the inspection is made on a routine basis and not under emergency conditions. Under emergency conditions the corresponding costs will be denoted B and $G(x)$. We will assume that A and B are positive constants and that $F(x)$ and $G(x)$ are continuous, non-decreasing and non-negative. Also $F(0) = G(0) = 0$. It is also reasonable to assume that $G(x) \geq F(x)$ and in many applications $G(x)$ will be considerably larger than $F(x)$ particularly for large x. Finally the model is completely specified by saying that the probability that an emergency occurs in the next T units of time is $1 - e^{-\Delta T}$, where $\Delta > 0$ and is known. A program now consists of a sequence of numbers $X = (x_1, x_2, \ldots)$. Routine inspections are made at the times $x_1, x_1 + x_2, \ldots \sum_1^n x_i$ where the emergency occurs

between times $\sum_{1}^{n} x_i$ and $\sum_{1}^{n+1} x_i$ and emergency inspection is made at time T, the time of the emergency.

The total costs of inspection and repairs from the beginning of the program until the emergency is met is

$$\sum_{i=1}^{n} (A + F(x_i)) + B + G(x^*),$$

where $x^* = T - x_n$. This is a random variable since T is a random variable (which also forces n to be a random variable)."

Savage proceeds to show solutions under various assumptions and indicated that certain of the equations can be solved for minimum expected costs by numerical methods.

It is believed that in surveillance work, the cost of routine inspection and repair can be approximated rather closely and that some probability of an "emergency", as used by Savage, can be set. The cost G(x) is essentially the cost of the final inspection and repair of an item before issuing it to a using unit. For large, complex equipment (aircraft in "mothballs", tanks, trucks, etc.) there is some prior knowledge of "demothballing" costs. Now if these costs can be related to time by some reasonable equation it should be possible to establish an optimum program of inspection and repair.

There are other factors involved in the selection of a sampling plan for surveillance purposes besides the cost factors. There is always the necessity to accomplish the military mission. No plan, regardless of how economical it may be of manpower and money, can be tolerated unless it will assure that the critical items will be in serviceable condition whenever needed. Thus, the original objective stated at the beginning of this paper is the crucial test of any proposed plan.

6. Disposition

Throughout this paper it has been assumed that after the inspection of stored items has been accomplished a decision will be made regarding the disposition of the items. The decisions, as enumerated previously, may be to:

1. Retain the item in stores without further rework or repair.
2. 100% inspect the items and repair those below acceptable quality standards.
3. Disassemble and repair or rework all the items.
4. Declare the items unusable and nonreparable and submit them to the disposal officer for salvage, sale, or scrap.

It should be realized that the decisions, other than the first to retain the items in stores without rework, may not automatically provide for the immediate inspection and repair of reparable items or the disposal of items beyond repair. There are many rules and regulations in all of the service branches that must be complied with and procedures that must be followed in order to accomplish the rework or disposal. Usually a separate agency, other than the warehousing agency, will be responsible for repair and overhaul. These agencies have their own budget limitations and priority lists of work to be accomplished which they must follow in attempting to maintain the fighting strength at the desired level. Thus, the relative quantity of usable items on hand compared to the prospective needs may determine the action to be taken. If the item is in short supply and the stock has been declared unusable but reparable , the priority classification may enable the maintenance activity to put this item into repair shops immediately. On the other hand, if the supply of usable items available exceeds the war reserve minimum stock level, the declaration of some quantity as unusable but reparable may not result in any maintenance work on those items. The reparable items may remain in the same condition for periods of a few months to several years before the usable stock becomes small enough to warrant repair of unusable items. Reparable items may be removed from

the surveillance program and as a result deteriorate at a more rapid rate so that repair at a later date may be more expensive than if it had been done earlier, but it may never have to be done at all. The availability of funds, manpower, and physical facilities are limitations within which repair and maintenance work must be carried out. Work schedules must be established months in advance and outside contractors may not be available.

These difficulties are part of the management problems that must be considered in the overall surveillance program. Each service should examine its practices and procedures very carefully to determine how its rules and procedures are contributing to the inefficiencies of the system. Some of the rules are necessary as safeguards against several types of errors that might be made by people at lower echelons and must be retained. Some of the difficulties arise from the frequent changes in weapons, equipment, and items of supply and from the rapidly changing military situations which regulate the needs for reserve stock. For example, a given model of airplane may be phased out over a period of years and for various reasons not use all of the spare parts that were originally purchased for that model. Care must be exerted to keep from expending money unnecessarily on the surveillance of spare parts that will not be needed for the few remaining planes of that type.

7. Classification of Material

A single surveillance plan probably cannot be designed that will meet the requirements of all the different situations that will be encountered. A number of plans, each with different features, should be available, but there should also be available some sort of guide lines by which the best surveillance plan for any given situation can be selected. The selection must be based upon a number of factors. It is recommended then that a number of classifications of material based on these factors be worked out so that appropriate inspection plans can be chosen for each category as a matter of policy.

One classification should deal with the sensitivity of the item

to age. This classification need only contain a small number of levels of sensitivity to indicate the relative frequency of inspection. About four levels should provide sufficient distinction:

Highly sensitive

Sensitive

Relatively inert

Inert

A shelf life could be associated with each level of sensitivity to give a better means of classifying the materials. The shelf life should be based on some standard condition, as for instance a covered warehouse without humidity control or special preservation. Then with special preservation or environmental control the item could be downgraded on the scale accordingly. For example, the highly sensitive level might be assigned a shelf life of 3 to 9 months, but an item so classified might have a shelf life of two or three times that length of time if it were afforded some special preservation. Then the properly preserved item might be classed as a sensitive item, with a shelf life of 10 to 30 months.

The item should also be classified according to how critical it is in the hands of the using organization and how many are issued to a unit. The following classification illustrates the concept:

Critical: every unit must be in good working condition at time of issue. No chance for using-unit to repair or replace the item. Military mission depends upon that item being serviceable. One issued at a time.

Sub-critical: every item must be in good working condition at time of issue or reparable with simple field tools commonly carried by the unit and with the skills usually available in the unit. One issued at a time.

Multiple, non-reparable issue: issued in quantities (hundreds, gross, cases, etc.,) very small defectiveness can be tolerated, but defectiveness not reparable in field. Too high a defectiveness impairs military strength.

Multiple, reparable issue: issued in quantity, defectiveness is reparable in field with commonly available tools. Defectiveness delays build-up of military strength of unit.

Large quantity issue - expendable, non-reparable: items issued in large quantity to each unit. High defectiveness is a nuisance but only critical in time of shortage of supply.

Along with the preceeding classification, it may be desirable to classify the items as to nature, such as expendable war materials (ammunition, bombs, rockets, wire, etc.), capital items (guns, airplanes, compressors, generators, etc.) or subsistence (foods, clothing, bedding, etc.). This classification should be extended in order to care for the material needs of all the services.

Another classification based upon the nature of the item might be used along with the previous classifications. This classification would be based upon the complexity of the item. Thus, items could be classified as:

Individual items (components, material, food, gasoline, oil, powder, socks, shirts, single replacement parts, etc.) all one material.

Simple assemblies (ball bearings, electron tubes, walkie-talkies, rifles, pistols, etc.) involving two or more pieces of two or more materials.

Large, non-complex assemblies (trucks, cranes, diesel engines, motor generator sets, small boats), large items involving a large number of parts and materials, representing a variety of preservation problems, but not particularly sensitive to aging if afforded normal care.

Large complex assemblies: (radar sets, airplanes, landing craft, P.T. Boats, Ground Control Navigation and Landing equipment), large items requiring specialized service personnel, complex test equipment, and special preservation and protection while stored.

It will be noted that this classification is really based upon the difficulty of maintenance in stored state. The more complex the equipment,

the larger the number of separate specifications that must be checked and complied with. The presence of such items as rubber hoses or gaskets in a larger item may alone increase the frequency of inspection two or three fold because of the sensitivity of the rubber to age. Precision bearings or working surfaces that may rust or corrode may have similar effects. Thus the more complex the item, the more surveillance effort must be expended.

A further classification of the item may be based on the kind of inspection required during the surveillance period. The inspection required is really a function of the complexity of the item and the sensitivity of its components to age. The inspections might be classified as:

Visual (does not involve the removal of preservation material. As long as the preservation materials are intact, the item can be assumed to be serviceable.)

Detailed (Preservatives are removed and the item components are minutely examined for deterioration. If satisfactory, the item is represerved.)

Disassemble and inspect (involves complete teardown of the item and minute examination of the individual parts for deterioration.)

These classifications are indicative of the factors that must be considered in establishing the surveillance program for any item of war reserve material, but only military personnel who are completely familiar with the material, its uses and requirements will be competent to prepare the final classifications to be used. If all the items of reserve stocks are then classified accordingly, there will be a basis for selecting sampling plans that will maximize the probability of accomplishing the desired protection. The various sampling plans must also be classified according to the same classifications, so that the selection of the plan will be a simple matter of matching the requirements of the material against the abilities of the various plans.

8. Summary and Recommendations

The successful surveillance of stored items is essentially a

management problem that depends upon having adequate and accurate information about the items involved, the costs incurred both in the surveillance program and procurement of the items, proper standards of quality for the items, and satisfactory sampling procedures to determine the condition of the stock. The development of a satisfactory program must require considerable time because a great amount of the necessary information is not available, or is of doubtful accuracy. Consequently, part of the program should be directed toward the accummulation and analysis of the information so that constant improvement in the surveillance program can be accomplished.

In order to accomplish the objectives of the surveillance program as outlined in this paper, the following steps are recommended:

1. A system of classifying all military items should be developed that will take into account the sensitivity of the item to age, number normally issued, the critical nature of the item, its complexity, and the nature of the inspection required while in storage;
2. All items in the Federal Cataloguing System should be classified according to the classification system established in 1;
3. Specifications of satisfactory or usable quality should be established for each class of item and an AQL and LTPD which represents the risk that can be tolerated should be established by classes.
4. A series of sampling plans, representing lot-by-lot, continous, and sequential types, should be selected and classified according to the same system as mentioned in the first recommendation;
5. Procedures should be formulated by which information regarding costs of surveillance, costs of procurement and repair, and deterioration rates under different storage and protection conditions can be accumulated.
6. The results of the surveillance program (information of defectiveness, deterioration, cost of inspection, etc.) should be analyzed periodically and the results used to adjust the surveillance

program as necessary. Classifications may be changed, AQL's and LTPD's may be increased or decreased, stock levels may be adjusted, or other changes may be made to provide the desired protection of stored items at lower net over-all cost to the government.

APPENDIX A

Results of Questionnaire

We sent a questionnaire to a number of individuals in different branches of the armed services in order to obtain some basic information about the current thinking on surveillance of stored items. These questionnaires gave a fair cross section of the practices and procedures of the different branches and, at the same time, pointed up some of the problems that must be solved in establishing a satisfactory surveillance program. Three of the sets of answers are reproduced here. These are fairly typical of those received.

Questions	Army	Navy Ordnance	Air Force
What department(s) of your branch of the service are most concerned with this problem?	The Deputy Chief of Staff for Logistics and the seven Technical Services under his command have primary interest in the surveillance of stocks. The seven Technical Services are Chemical, Engineers, Medical, Ordnance, Quartermaster, Signal and Transportation.	Within the Bureau of Ordnance the Quality Control Division, The Planning Division, and that branch of the Material Division having charge of issuance of ordnance stores are primarily concerned with this problem.	Hq AMC, Directorate of Maintenance Engineering, Directorate of Supply, Directorate of Transportation and Services. Directorate of Plans and Programs, and Quality Control Office.
Do you have a specified plan by which the stored items are periodically inspected? Who is responsible for administering such plan or plans?	The technical services have specific plans governing the periodic inspection of Reserve Stocks. Administration of the plan varies among the services. While all delegate local Administration to the Depot Commander, a few have also assigned overall responsibility to their central Stock Control Points.	Yes, for most ordnance stores, a plan for periodic inspection is in use. Overall administration of the plan rests with the Quality Control Division of the Bureau with implementation by Quality Evaluation Laboratories located at certain of the naval activities.	Yes. Responsibility of the AF depot having prime maintenance responsibility of the items (property class).
Do you have a special set of specifications the same as those used in procurement?	All of the Technical Services have developed specifications for the surveillance of assigned items. Specifications covering procurement and surveillance are similar for most items, however, due to peculiarities of certain items it has been necessary to develop additional criteria to cover these items.	Special specifications and inspection procedures are used in surveillance which, in general, follow those used in procurement, although tolerances may be somewhat looser.	The T.O. 00-[illegible] series (Incl. no. [illegible]), AMCM [illegible]-17 (Incl. no. 5), AMCM [illegible] (Incl. no. 6), and AF Manual [illegible] (available for reference at any AF depot).
Who set standards against which the stored items are inspected?	The approved standards by which stored items are checked are established by the Chiefs of Technical Services from information developed by their Engineering Divisions.	The Bureau of Ordnance sets or approves standards whereby stored items are inspected.	Directorate of Maintenance Engineering and Services at prime maintenance depot, as listed in T.O. 00-[illegible] series.

Questions	Army	Navy Ordnance	Air Force
Is there a systematic data collection plan for accumulating information on the rate of deterioration under varying environment?	Four of the seven Technical Services at present have a systematic data collection plan for accumulating pertinent information as a result of surveillance inspections.	There is a systematic plan for accumulating information on quality of material and rate of deterioration. For most items existing storage conditions are utilized; however, there are special cases where accelerated aging tests are conducted under unusual conditions.	Not at present. Proposed AF Regulation will implement a procedure to furnish such data.
Who does the periodic inspection?	Periodic inspections of reserve stocks is a coordinated effort between Storage Division and Inspection Personnel at the depots. Representatives of the Chief of Technical Service also conduct spot checks during their technical inspections of depots.	The periodic inspection is conducted by the staff of the Quality Evaluation Laboratory responsible for the particular stocks.	By depot supply and maintenance inspectors.
What are the possible decisions (dispositions) after the inspection?	The possible dispositions of stock inspected are as follows: 1. Serviceable - returned to stock for issue. 2. Unserviceable - a. Reparable - repair and return to stock. b. Uneconomically reparable - initiate disposal action. All material is classified in accordance with Condition Reservation Codes set forth in Army Regulation.	Decisions may be to declare the material serviceable or unserviceable subject to further dispositions such as converting, reworking, screening, destroying.	Item is acceptable - program for repair - and/or condemn.
Is the inspection a sampling or a 100% procedure?	Inspection of stored items is normally made by sampling, however, when sampling reveals an excessive number of defects a 100% inspection is accomplished.	A sampling inspection is used for surveillance.	Either 100% or sample inspection, dependent upon the commodity.

Questions	Army	Navy Ordnance	Air Force
Who is responsible for repair or overhaul of items that are not usable?	The responsibility for repair or overhaul is that of the maintenance activities of the depots.	The Bureau of Ordnance administers directions for repair, overhaul or other disposition of the unusable material.	Directorate of Maintenance Engineering and Services of the holding depot.
Will repair or overhaul occur immediately after the items are declared unusable? What are the determining factors?	Minor repairs or overhauls are normally completed in a short time. Major repairs or overhauls are usually accomplished by priority scheduling. The priority of repair is determined by item, stock position, degree of repair, etc.	The repair or overhaul may or may not occur immediately after the item is declared unusable. If there is an oversupply of the material on hand the defective material may be stored as unserviceable until requirements make it necessary to overhaul. In other cases a shortage of supply may dictate immediate overhaul or rework.	Not always immediately - determining factor for repair is the need to meet stock level requirements for the item and whether the item can economically be repaired
Is there any formal way by which the risk of issuing defective material (in an emergency) is evaluated?	There is no prescribed method by which the risk of issuing defective material may be evaluated. However, most of the services do recommend that depots make a sample inspection of sensitive items and items found to be questionable during the last surveillance inspection.	The operating characteristic curves of the sampling plans used provide the means whereby risks of the sentencing decision (serviceable or unserviceable) for any quality of stock is stated. Should known unserviceable material be required for an emergency situation, the expected loss involved in issuing this defective material to the using services is ordinarily not known.	Deviation is permitted by [illegible] by referral to the prime maintenance depot.
How is such a risk stated?	The risk is stated in percent defective or number of defects per 100.		Based upon individual cases, stated by correspondence (in writing) with limitations as to quantity, [illegible], etc.
Does the amount of war reserve material required to be in usable condition change from time to time? What are factors involved?	The amount of war reserve material required to be in a usable condition varies from time to time. Factors which influence changes in the items and the amounts to be held in reserve are as follows: 1. Changes in mobilization requirements 2. Obsolescence of items. 3. Standardization of new items. 4. Production capabilities.	It is presumed that conditions governing the amounts of usable war reserve material require change from time to time.	The war reserve material is all required to be in usable condition. However, dependent upon the flying program, the amount in war reserve does vary.

Question	Army	Navy Ordnance	Air Force
Does existence of [illegible] surplus affect the surveillance inspection and maintenance program?	The existence of surplus supplies does not affect the surveillance procedures. In some cases it does increase the maintenance workload.	The surveillance inspection program is organized to evaluate stocks on hand, whether needed immediately or for future usage. Decisions as to serviceability will affect the status of stocks, and it is possible that stocks requiring repair or maintenance work will be set aside in a non-ready state for future renovation. This procedure naturally will lessen the quantity of material on which future surveillance is conducted. The Bureau does not ordinarily qualify segments of stocks as surplus.	Not affected by periodic inspection.

APPENDIX B

SAMPLING FROM MIXED LOTS

Sampling from mixed lots is ordinarily considered a dangerous practice because the usual assumptions regarding homogeneity, normality and so forth cannot be made. Lack of some prior knowledge of the cause system by which the lot was produced eliminates one of the bases on which conclusions regarding the distribution can be drawn from samples. On the other hand the surveillance of stored items frequently involves a mixture of lots of similar product that cannot be separated because the identity of the lots has been lost or because the cost of reassembling the lots would be prohibitive. The question then arises as to how great are the hazards of sampling from the mixture.

In order to arrive at some experimental conclusions about the hazards of sampling from a mixture of lots, two different mixtures of lots were prepared and submitted to sampling both by variables and attribute lot-by-lot acceptance plans. One mixture was composed of three lots, each approximately normally distributed, but with different means and standard deviations. There were 500 chips in each lot, making a total of 1,500 chips in the mixture. This mixture is referred to as Mixture A. Figure I shows the distribution of the three lots and the distribution of the total mixture.

Mixture B consisted of three lots of non-normally distributed values. The lots contained 74, 135, and 71 chips, making a total of 280 chips in the mixture. Figure II shows the distributions of the lots and the mixture.

The tolerance limits on each of these mixtures can be set in order to give any fraction defective desired for an experimental sampling test. Two different sets of tolerance limits were used for each mixture. One set of limits gave a relatively low fraction defective and the other gave a higher fraction defective.

Attribute Sampling - Mixture A.

The tolerance limits for the Mixture A were first set so that p' = 1.53% defective and then so that p' = 7.54% defective. A MIL STD 105A sampling plan, level I, AQL = 2.5, Code Letter J was chosen. This plan calls for a sample size n of 75, with an acceptance number c of 4 . Twenty samples of 75 were drawn randomly from the mixture with the 1.53% defective limits and the number of defectives recorded. In all twenty cases the sampling plan accepted the lot. This result was expected because the O.C. curve for the plan shows that 2% defective would be accepted with a probability of 0.95+ .

Twenty samples of 75 chips were then drawn from the mixture with the 7.54% defective limits. In this case the sampling plan accepted only 4 lots and rejected 16 . This result was somewhat better than expected, because the O.C. curve shows that lots 7.5% defective would be accepted with a probability of about 0.30 , whereas this test accepted only 20% of the lots.

Attribute Sampling - Mixture B.

The tolerance limits for Mixture B (280 chips) were first set to give p' = 3.93% and then 5.72% . The Level I, 4.0% AQL, Sample Size Code Letter F plan was selected from MIL STD 105A . This plan calls for a sample size of 15 with an acceptance number c of 1 . Twenty samples of 15 were drawn randomly from the mixture with the lower fraction defective. One of the twenty lots was rejected by the sample results.

Twenty samples of 15 chips were drawn from the mixture with the tolerance limits set to give p' = 5.72% . Six lots of the twenty were rejected by the sampling plan. The results in both of these tests correspond very closely to the probabilities of acceptance as indicated by the O.C. curve for the plan used.

These results indicate that sampling from mixtures of lots, where there is reason to believe that they originally were similar is not particularly hazardous. The protection derived from such attribute plans in this case is exactly like that derived from use of the plans for

procurement acceptance. The protection is derived from applying the sampling plan to a large number of lots, so that the overall quality accepted is assured, but "good" individual lots may be rejected occasionally, and "bad" individual lots may be accepted occasionally. This points up the desirability of using plans with a steep O.C. curve to avoid the occasional acceptance of lots that are much worse than the established AQL.

Variables Sampling - Mixture A .

Twenty samples of twenty chips each were randomly drawn from the Mixture A , and the values were recorded. $\bar{X}$ and R were computed for each sample, and σ' was estimated by the formula $\sigma' = \frac{R}{d_2}$, for each sample. $\bar{X} \pm 3\sigma'$ was compared with the actual limits of the Mixture A distribution. In 15 samples (75%) less than 1% of the original mixture was outside of the limits estimated from the samples. Of the remaining 5 samples the estimated limits contained 98.5% or more of the original mixture. Table III shows the average $\bar{X}$ and the $3\sigma'$ limits for the 20 samples, along with the number of items falling outside of these estimated limits.

Variables Sampling - Mixture B.

Twenty samples of ten chips each were drawn randomly from the Mixture B. $\bar{X}$ and R were recorded for each sample and σ' was estimated using $\sigma' = \frac{R}{d_2}$. Again the estimated limits were compared with the actual limits of the Mixture. In 16 cases the estimated limits were wider than the actual limits. In the other four cases the number of items lying outside the estimated limits were 1, 13, 24, and 62. It is obvious that an error of 62 out of a mixture of 280 values is too large to be tolerated frequently, but this was a very unlikely event that would not happen very frequently in such sampling.

Comments on Experiment.

Twenty samples is too small a number from which to draw any very reliable conclusions regarding the reliability of a method. On the other hand, examination of the distribution of the mixtures reveals that the shapes are not radically different from normal curves. It has been proved that the means of samples drawn from any distribution tend to be normally distributed. Thus, we could expect the means of samples drawn from a mixture to center around mean of the mixture. Furthermore, the measures of dispersion, whether σ or R, of the sample gives reasonable reliable estimates of the dispersion of the mixture. It is of course improper to attempt to place numerical probabilities on the number of items that will fall within some multiple of σ'. However, Tchebycheff's inequality can be used to indicate the bounds of the mixture, if it is necessary to impose strict probability limits.

TABLE I - Distribution of Mixture A

Chip No.	Lot # 1	Lot # 2	Lot # 3	Mix A
4	1			1
5	1			1
6	1			1
7	1			1
8	2			2
9	4			4
10	6			6
11	8			8
12	11	1		12
13	15	2		17
14	19	5		24
15	24	11		35
16	29	22	1	62
17	33	39	2	74
18	36	58	5	99
19	39	73	11	123
20	40	78	22	140
21	39	73	39	157
22	36	58	57	152
23	33	39	73	145
24	29	22	78	129
25	24	11	73	108
26	19	5	58	82
27	15	2	39	56
28	11	1	22	34
29	8		11	19
30	6		5	11
31	4		2	6
32	2		1	3
33	1			1
34	1			1
35	1			1
Total				1500

TABLE II - Distribution of Mixture B

Chip No.	Lot #4	Lot #5	Lot #6	Mix B
5	1			1
6	2			2
7	5			5
8	7	1		8
9	8	1		9
10	9	2		11
11	9	3		12
12	9	5		14
13	8	6		14
14	7	7	1	15
15	5	8	2	15
16	3	9	7	19

Chip No.	Lot #4	Lot #5	Lot #6	Mix B
17	1	9	9	19
18		10	10	20
19		10	10	20
20		9	10	19
21		9	9	18
22		9	7	16
23		8	3	11
24		8	2	10
25		7	1	8
26		6		6
27		5		5
28		3		3
Total				280

TABLE III Sample Results from Mixture A (Actual Limits 4 through 35)

Sample No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
$\overline{X}$	21.9	20.3	20.5	23.3	22.5	19.5	21.6	20.7	21.5	19.4	22.3	21.6	20.4	20.2	20.9	20.7	21.7	20.7	23.6	19.9
R	19	15	17	21	18	2	12	26	13	21	19	18	16	16	13	18	15	13	15	19
$\overline{X} + 3\sigma'$	37.2	32.4	34.2	40.1	37.0	37.3	31.3	41.6	32.0	36.3	37.5	36.0	33.3	33.1	31.3	35.1	33.7	31.1	35.6	35.1
$\overline{X} - 3\sigma'$	6.7	8.2	6.9	6.4	8.0	1.9		0	11.0	2.5	7.0	7.1	7.5	7.3	10.5	6.2	9.6	10.2	11.5	4.6
Items outside estimated limits	3	9	4	2	4	0	22	0	22	0	3	3	7	6	22	2	11	22	24	1

TABLE IV Sample Results from Mixture B (Actual Limits 5 through 28)

Sample No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
$\overline{X}$	15.1	15.3	15.6	15.5	17.0	19.0	17.6	16.1	15.5	16.5	19.1	19.7	16.4	18.7	19.4	17.5	16.9	17.9	15.9	13.9
R	18	15	18	16	16	13	17	21	15	22	21	20	12	7	22	9	19	13	19	13
$\overline{X} + 3\sigma'$	32.7	29.9	33.2	31.1	33.2	31.7	34.2	36.6	30.1	37.9	39.6	39.2	28.1	25.5	40.3	26.3	35.4	30.6	34.4	26.6
$\overline{X} - 3\sigma'$	0	.7	0	0	2	6.3	1.0	0	0.8	0	0	.2	4.7	11.3	0	8.7	0	5.[illegible]	0	1.2
Items outside estimated limits	0	0	0	0	0	1	0	0	0	0	0	0	0	62	0	24	0	0	0	13

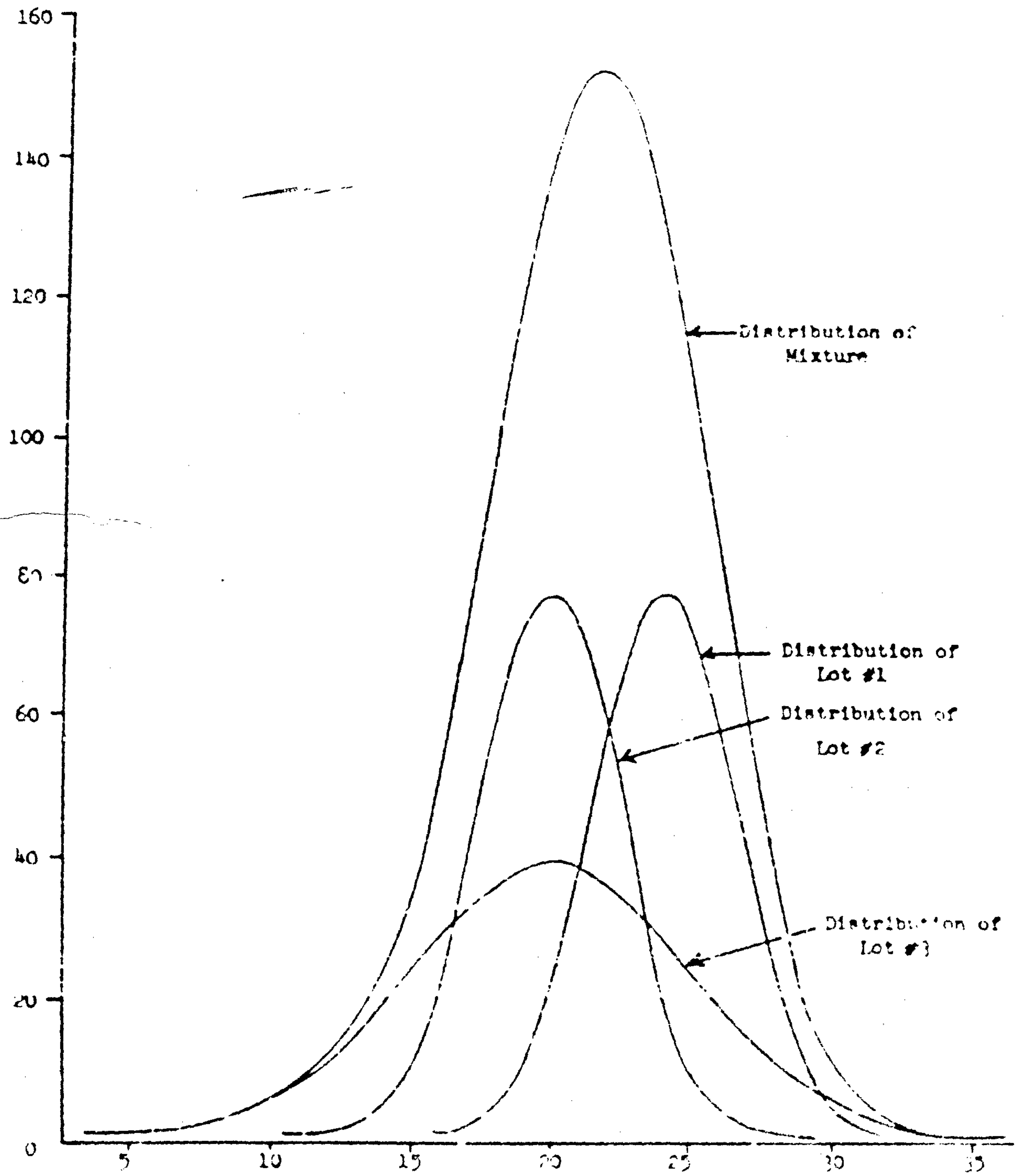

Figure I - Distribution of Mixture A

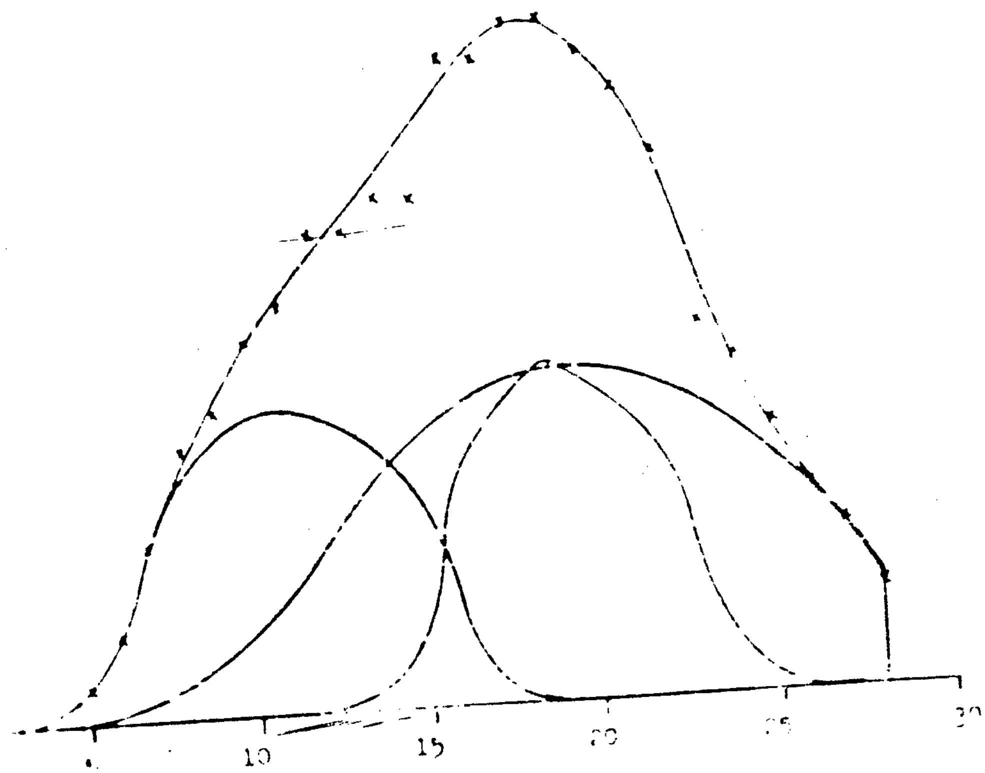

Figure II-Distribution of Mixture B